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Abstract: Ice Mile swimming (1608 m in water of below 5 ℃elsius) is becoming increasingly popular. This case study aimed to identify body core temperature and selected haematological and biochemical parameters before and after repeated Ice Miles. An experienced ice swimmer completed three consecutive Ice Miles within 15 h. Swim times, body core temperatures, and selected urinary and haematological parameters were recorded. Body core temperature reached its maximum between 5, 8 and 15 min after immersion (37.7℃, 38.1℃, and 38.0℃, respectively). The swimmer suffered hypothermia during the first Ice Mile (35.4℃) and body core temperature dropped furthermore to 34.5℃ during recovery after the first Ice Mile. He developed a metabolic acidosis in both the first and the last Ice Mile (pH 7.31 and pH 7.34, respectively). We observed hyperkalaemia ($[K^+] > 5.5$ mM) after the second Ice Mile (6.9 mM). This was followed by a drop in $[K^+]$ to3.7 mM after the third Ice Mile. Anticipatory thermogenesis (i.e. an initial increase of body core temperature after immersion in ice cold water) seems to be a physiological response in a trained athlete. The results suggest that swimming in ice-cold water leads to a metabolic acidosis, which the swimmer compensates with hyperventilation (i.e. leading to respiratory alkalosis). The shift of serum $[K^+]$ could increase the risk of a cardiac arrhythmia. Further studies addressing the physiology and potential risks of Ice Mile swimming are required to substantiate this finding.

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Swimming Three Ice Miles within Fifteen Hours

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Abstract

Ice Mile swimming (1608 m in water of below 5 °Celsius) is becoming increasingly popular. This case study aimed to identify body core temperature and selected haematological and biochemical parameters before and after repeated Ice Miles. An experienced ice swimmer completed three consecutive Ice Miles within 15 h. Swim times, body core temperatures, and selected urinary and haematological parameters were recorded. Body core temperature reached its maximum between 5, 8 and 15 min after immersion (37.7°C, 38.1°C, and 38.0°C, respectively). The swimmer suffered hypothermia during the first Ice Mile (35.4°C) and body core temperature dropped furthermore to 34.5°C during recovery after the first Ice Mile. He developed a metabolic acidosis in both the first and the last Ice Mile (pH 7.31 and pH 7.34, respectively). We observed hyperkalaemia ($[K^+] > 5.5$ mM) after the second Ice Mile (6.9 mM). This was followed by a drop in $[K^+]$ to3.7 mM after the third Ice Mile. Anticipatory thermogenesis (*i.e.* an initial increase of body core temperature after immersion in ice cold water) seems to be a physiological response in a trained athlete. The results suggest that swimming in ice-cold water leads to a metabolic acidosis, which the swimmer compensates with hyperventilation (*i.e.* leading to respiratory alkalosis). The shift of serum $[K^+]$ could increase the risk of a cardiac arrhythmia. Further studies addressing the physiology and potential risks of Ice Mile swimming are required to substantiate this finding.

Key Words: body fat, hypothermia, open-water swimming

Introduction

Swimming races are mainly held as indoor pool competitions (18, 30), but can also be held as open-water competitions. Open-water swimming, such as the 'English Channel Crossing', is of increasing popularity (8). Similar trends have been observed in freshwater and indoor ultra-endurance swimming, where the number of participants and finishers has increased in recent years (7, 9, 19, 20).

A rather young discipline in open-water swimming is the so-called Ice Mile swimming. It is defined as swimming a distance of 1608 m in water temperatures at or below 5°C. The swim must be unassisted and the swimmer must wear one pair of goggles, a cap and a standard swimming costume.[1]

Important issues in cold-water swimming are afterdrop (*i.e.* the fall in body core temperature after a performance in the cold). The usual core temperature of healthy rested adult humans ranges between 36.5°C and 37.5°C. Physiological hypothermia is defined as a body core temperature equal to or lower than 36.0°C (13).

Hypothermia during or after ice swimming (*i.e.* afterdrop) presents a great danger with potentially fatal consequences (10). A study published in 1946 showed that people immersed in water colder than 6°C after a shipwreck usually died of hypothermia within 75 min (24). In 1969, Keatinge *et al.* conducted several studies investigating the dangers of swimming in cold water (15). These authors concluded that swimming in cold water had be abandoned partly

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[1] International Ice Swimming Association (IISA), www.internationaliceswimming.com
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because of respiratory reflexes in thin men shortly after immersion (*i.e.* skinfold thickness less than 8 mm) and due to hypothermia in overweight men (*i.e.* body mass index, BMI, higher than 25 kg/m² and skinfold thickness thicker than 9.5 mm) (15). Afterdrop was investigated in 11 subjects following the 'New Year's Day Alcatraz Swim' competition in January 1998, where hypothermia was observed in only one subject and afterdrop in 10 of the 11 subjects (26).

However, it is possible that low body core temperature is beneficial. With increasing frequency, hypothermia is used to prevent or mitigate various types of neurologic injury (27). Side effects of hypothermia include immunosuppression with increased infection risk, cold diuresis and hypovolemia, electrolyte disorders, insulin resistance, impaired drug clearance, and mild coagulopathy (27). A risk of clinically significant arrhythmias occurs only if core temperature decreases below 30°C (26, 27).

Only a few scientific studies investigating body core temperature during swimming in water colder than 5°C do exist (6, 15, 21, 25). For example, Noakes *et al.* reported body core temperature responses in a single individual to swims of 1 km or longer in ice cold water (0 – 3°C), where they found that the swimmer was able to maintain a body core temperature above 36°C during a swim of 30 min in water at a temperature of 2 – 3°C (25). Similarly, in a case study with one swimmer successfully completing two Ice Miles body core temperature dropped 50 min after swimming one Ice Mile to 34.5°C (21).

As far as we know, no athlete ever tried to swim repeatedly in ice cold water and no study investigated how hematological and biochemical parameters, electrolytes and pH-value react to such an extreme environment. In the present case study, we followed an experienced ice swimmer who intended to swim as many Ice Miles as possible in a row within 24 h.

Materials and Methods

Ethics Approval

The experiment was approved by the Ethical Committee of the Kanton St. Gallen, Switzerland, and the swimmer gave his informed written consent for data collection and publication of the data.

The Subject

The subject was an experienced open-water ultra and ice swimmer (57 years old, 103 kg body mass, 1.76 m body height, 33.2 kg/m^2 BMI). He was the first swimmer ever to cross the Fehmarn-Belt from Fehmarn (Germany) to Rødby (Denmark) and back to Fehmarn (*i.e.* double crossing, 2 × 25 km, 16°C water temperature) in 2011.[2] In 2012, he completed a 6-h swim in water colder than 10°C (28). In 2015, he swam two Ice Miles in water colder than 5°C (21). The subject was without any previously diagnosed medical conditions, was not taking any medication and no history of non-freezing cold injury such as loss of sensation, skin damage/infection, or nerve damage (21, 28).

The Event

The experiment was designed as a case study with one participant. The athlete started the first Ice Mile on February 6, 2016, at 00:45 a.m. in the harbor of Paderborn at the Lake Lippe, Germany. The water had a temperature of 4.7-5.0°C one meter below surface. For each Ice Mile, the swimmer was followed by two rescue boats. Two experienced divers were ready for immediate rescue, if needed. A medical team was also on board. After each Ice Mile, the swimmer left the water to recover.

Methods

Given the results from several trainings prior to this event shown in Table 1, we hypothesized that it would be possible to swim five Ice Miles within 24 h and each Ice Mile should take about 40 min to complete. The longest interval from starting an Ice Mile to recovering to 37°C body core temperature was 4:36 h:min. We planned that the athlete would complete as many Ice Miles as possible in daylight and therefore, the first start was set to 00:45 a.m. The intervals of the starts of the different Ice Miles were set between 4:30 h:min and 6:00 h:min. The swimming distance was measured using a GPS unit (Spot Gen3 Satellite messenger, www.findmespot.eu/gm). During all Ice Miles, the athlete wore his swimming trunks and swimming goggles.

Before (15 min) and after (20 min) each Ice Mile, we measured selected blood and urine parameters. We measured body core temperature continuously using the thermoelectric probes Endotherm® (EndoTherm GmbH, Arlesheim, Switzerland). Endotherm® measures temperatures from −40°C to +85°C with a resolution of 0.0625°C and a precision of 0.1°C. The Endotherm® probes were programmed to take one measurement every 30 s. The probes were applied 2:45 h:min before the start of the first swim. The probe was inserted in the rectum using a protective container provided by

[2] www.welt.de/regionales/stuttgart/article13511181/Stuttgarter-schwimmt-durch-Fehmarnbelt.html

Table 1. Trainings prior to the event

Date	Location	Water T [°C]	Air T [°C]	Starting time [min:sec]	Body core T at start [°C]	Time maximum T [min:sec]	Maximum T °C	Finishing time [min:sec]	Body core T at finish [°C]	Time lowest T [min:sec]	Lowest T [°C]	Time reaching 37°C [min:sec]	Body core T [°C]	Distance [m]	Swim duration [h:min:sec]	Body mass [kg]	BMI [kg.m^{-2}]
26/09/15	Lippesee	15.85	16.8	10:44	37.58	11:30	38.07	11:38	38.07	12:54	36.83	13:32		2100	0:54:00	95.2	30.7
03/10/15	Plüderhausersee	14.7	23	11:58	37.64	12:18	37.95	13:02	37.70	14:34	36.77	15:44	36.83	2600	1:02:00	95.5	30.8
05/10/15	Plüderhausersee	15.68	17	14:42	37.70	15:16	38.32	15:30	38.32	17:02	36.89			2100	0:58:00	96.2	31.1
08/10/15	Plüderhausersee	15.3	17.7	13:44	37.55	14:20	38.05	14:54	37.93	17:18	36.55			2600	1:10:00	96.5	31.2
10/10/15	Plüderhausersee	15.05	14.2	12:22	37.49	13:02	38.18	14:02	38.05	15:44	36.37			4200	1:40:00	96.6	31.2
11/10/15	Plüderhausersee	14.96	19.6	11:24	37.68	11:54	38.11	13:34	37.67	15:14	36.18			5200	2:07:00	96.6	31.2
17/10/15	Plüderhausersee	11.77	8.4	12:00	37.68	12:36	37.93	13:04	37.80	15:15	36.61			2500	1:04:00	95.9	31
18/10/15	Plüderhausersee	11.48	8.13	11:42	37.74	12:04	38.05	12:42	37.55	14:26	36.37			2300	1:00:00	95.8	30.9
21/10/15	Plüderhausersee	11.88	12	14:14	37.68	14:36	37.99	15:22	37.49	16:42	36.31	18:02	36.99	2700	1:08:00	95.9	31
24/10/15	Plüderhausersee	11.97	16.2	11:45	37.68	12:07	37.86	12:25	37.74	13:57	36.68	15:41	36.99	1100	0:40:00	97.4	31.4
25/10/15	Plüderhausersee	11.73	14.4	11:41	37.99	12:05	38.24	12:41	37.93	13:47	36.93	15:05	36.99	2500	1:00:00	97.4	31.4
31/10/15	Plüderhausersee	10.75	11.1	12:30	37.87	12:54	38.05	13:38	37.80	15:18	36.68	16:18	36.99	2600	1:08:00	96.7	31.2
01/11/15	Plüderhausersee	10.71	14.6	12:34	37.74	13:00	38.11	14:34	36.87	15:14	36.43	16:52	36.99	4500	2:00:00	98.0	31.6
03/11/15	Plüderhausersee	9.8	8.62	14:04	37.80	14:28	37.99	14:52	37.68	15:42	36.68	17:20	36.99	2200	0:48:00	99.3	32.1
05/11/15	Plüderhausersee	10.31	16.5	14:00	37.68	14:16	38.05	15:02	37.49	16:26	36.11			2600	1:02:00	98.9	31.9
08/11/15	Plüderhausersee	11.62	18.3	11:50	37.87	12:12	38.11	13:56	36.99	15:06	36.06	16:26	36.99	5100	2:06:00	98.3	31.7
14/11/15	Lippesee	11.2	10.8	11:02	37.43	11:16	37.62	11:34	37.55	12:46	36.56	13:32	36.99	1000	0:32:00	99.4	32.1
17/11/15	Plüderhausersee	9.8	15	13:45	37.62	14:07	37.93	14:25	37.87	15:39	36.12	16:23	36.99	1600	0:40:00	99.8	32.2
19/11/15	Plüderhausersee	10.3	13.8	14:00	37.93	14:22	38.18	14:40	37.87	15:56	36.49			1700	0:40:00	99.8	32.2
21/11/15	Plüderhausersee	9.81	6.9	11:45	37.89	12:02	38.2	12:35	38.08	13:49	36.64			2300	0:50:00	98.6	31.8
22/11/15	Plüderhausersee	9.1	3.2	11:29	37.89	11:47	38.14	12:11	38.01	13:21	36.39			1500	0:41:00	100.0	32.3
28/11/15	Plüderhausersee	6.07	0.7	11:44	37.83	11:57	37.95	11:08	37.89	13:07	36.27	14:37	36.96	1100	0:24:00	100.0	32.60
29/11/15	Plüderhausersee	5.87	7.7	12:22	38.14	12:36	38.26	12:44	38.26	13:14	36.27	14:58	36.96	1180	0:22:00	100.0	32.60
02/12/15	Plüderhausersee	7.11	10.4	13:55	37.87	14:10		14:27	37.93	15:28	36.55	16:26	36.99	1240	0:32:00	100.0	32.3
04/12/15	Plüderhausersee	6.43	6.04	13:50	37.43	14:00	37.74	14:15	37.24	14:44	35.99	16:20	36.99	1080	0:25:00	101.2	32.7
06/12/15	Bodensee	7.35	8.47	15:00	38.16	15:00	38.16	15:45	37.60	16:28	36.67	16:56	36.98	1340	0:45:00	102.1	33
08/12/15	Plüderhausersee	5.93	4.38	11:06	37.70	11:24	38.01	11:31	38.01	12:16	36.7	13:56	36.99	1100	0:25:00	99.9	32.3
12/12/15	Plüderhausersee	5.36	11.3	12:20	37.83	12:34	38.01	12:47	37.64	13:32	36.15	14:56	37.02	1200	0:27:00	98.5	31.8
13/12/15	Plüderhausersee	5.4	9.41	12:40	37.95	12:44	38.01	13:08	37.64	13:40	36.27	15:34	37.02	1240	0:28:00	99.4	32.1
17/12/15	Plüderhausersee	5.6	11.30	7:12	-	-	-	-	-	-	-	-	-	1220	0:35:00	99.3	32.1
19/12/15	Plüderhausersee	5.74	9.30	11:17	-			11:55						1620	0:38:00	100.3	32.4
20/12/15	Plüderhausersee	5.7	10.20	14:16	37.79	14:32	38.04	14:49	37.79	15:38	35.49	17:42	36.98	1740	0:33:00	100.8	32.5
22/12/15	Plüderhausersee	5.58	12.60	10:35	37.85	10:48	38.10	11:00	37.98	11:34	36.42	12:52	36.98	1040	0:25:00	100.3	32.4
23/12/15	Plüderhausersee	5.68	9.50	13:15	37.17	13:26	37.48	13:40	37.23	14:16	35.98	15:42	36.98	1120	0:25:00	100.8	32.5
24/12/15	Plüderhausersee	5.83	13.54	13:15	37.18	13:18	37.60	13;46	37.04	14:24	35.48	-		1430	0:31:00	100.1	32.3
25/12/15	Plüderhausersee	5.95	12.70	12:15	37.11	12:31	37.73	12:43	37.73	14:37	35.55	15:43	36.98	1350	0:28:00	99.9	32.3
27/12/15	Plüderhausersee	5.16	12.41	12:40	38.23	12:50	38.29	13:12	37.92	14:02	36.42	12:57	36.98	1690	0:32:00	99.5	32.1
28/12/15	Plüderhausersee	4.8	6.38	12:25	37.92	12:40	38.04	12:40	38.04	14:44	36.73	15:12	36.98	580	0:15:00	99.5	32.1
29/12/15	Plüderhausersee	3.78	2.10	11:00	37.67	11:12	37.85	11:22	37.63	12:02	36.30	14:10	36.98	1120	0:22:00	100.1	32.3
30/12/15	Plüderhausersee	4.44	3.78	10:30	37.67	10:45	37.85	11:05	37.36	11:39	35.86	13:53	36.98	1160	0:25:00	99.9	32.3

T = temperature, BMI = body mass index

Table 2. Weather conditions

Weather	Start Mile 1	Finish Mile 1	Start Mile 2	Finish Mile 2	Start Mile 3	Finish Mile 3
Air temperature, C°	10.3	10	10.5	11.5	13.9	13.3
Water temperature, C°	4.7	4.7	4.8	4.8	4.9	4.9
Barometric pressure, hpa	1025.4	1024.5	1018.4	1018.2	1014.1	1014.2
Wind, beaufortscale	4	3	3	2	3	3
Wind, direction	south	southwest	south	southeast	southwest	south
Light, lux	0	0	34.2	33.3	23.9	18.6
UV-Index	0	0	1	2	1	1

the manufacturer. Tympanic temperature was measured after (5 min) the first two Ice Miles, using a resistance thermometer Cosinuss® sensor (Cosinuss°, München, Germany). After the third Ice Mile, it was not attached because of the distraction caused by a deep cut in the foot that he suffered from as he left the water. The blood samples were taken from the ear lobe and analysed using the i-STAT® (Axonlab, Baden, Switzerland) system using CHEM 8+ (*i.e.* [Na], [K], [Cl], TCO_2, anion gap, calcium, glucose, creatinine and haemoglobin) and CG4+ cartridges (*i.e.* pH value, CO_2, HCO_3, O_2, base excess). The urine samples (*i.e.* urine specific gravity, urine pH value, urine glucose, urine nitrite, and urine protein) were analysed using the Combur Test® (Roche, Basel, Switzerland). Moreover, we measured body composition employing the 'BC-568 Segmental Body Composition Analyser' (Tanita™, Tokyo, Japan) to determine body fat percentage, lean body mass, fat mass, bone mass and body weight. The analyser measures weight with increments of 0.1 kg and body fat increments with 0.1%.

Before the first Ice Mile he only drank a small sip of water and ate some sweets. Before the second Ice Mile he drank water, ate a slice of bread with cheese, sweets (100g = 67g carbohydrate, 10g fat, 2.4g protein) and a cookie. Before the third Ice Mile he drank a non-alcoholic beer and ate half a jar of plum butter (ca 250g = 125g carbohydrates), a soup and two pieces of cake.

The weather data (*i.e.* air temperature, barometric pressure hPa, wind beaufort-scale and wind direction, light intensity [lux] and UV-Index) was provided by the Deutsche Lebens-Rettungs-Gesellschaft, the largest voluntary lifesaving organization in the world.[3] The data were continuously measured by the weather station at the rescue station (Table 2). Water temperature was measured one meter below surface with three different thermometers using thermoelectric probes from Endotherm® (EndoTherm GmbH, Arlesheim, Switzerland) and LCD hand-operated thermometers DT-300 (Voltcraft, Hirschau, Germany) with a temperature accuracy of 0.1°C.

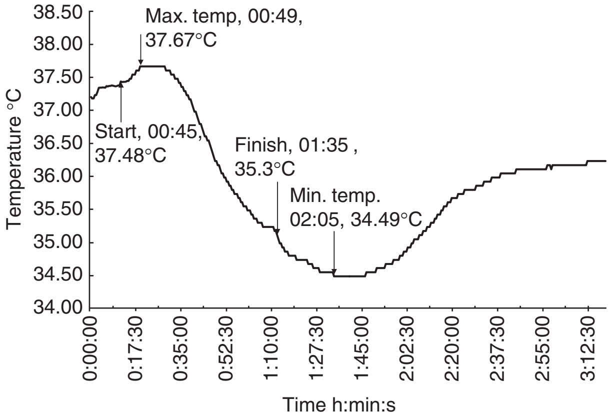

Fig. 1. Change in body core temperature during the first Ice Mile.

Results

The First Ice Mile

The subject started his first Ice Mile on February 13, 2016, at 00:45 a.m. at a water temperature of 4.7°C. During the swim, he lost orientation due to the darkness, which led to a prolonged swim time of 50 min. He changed between freestyle and breaststroke. At the start, his body core temperature was at 37.5°C and reached the maximum of 37.7°C after 5 min of swimming (Fig. 1). At the end of the Ice Mile, body core temperature had reached 35.3°C. Thus, he developed hypothermia during the swim. The lowest point was reached 30 min after leaving the water at

[3] Deutsche Lebensrettungsgesellschaft, www.dlrg.de

Table 3. Blood parameters, bio impedance and urinary parameters before and after the first Ice Mile

Parameters	Pre	Post	Change absolute	Percent change	Reference Range Arterial
Sodium, mM	139	139	0	0.00%	138-146 mM
Potassium, mM	5	5.1	0.1	1.96%	3.5-5.5 mM
Chloride, mM	108	111	3	2.70%	98-109 mM
TCO_2, mM	21	15	-6	-40.00%	24-29 mM
Anion Gap*, mM	16	19	3	15.79%	10-20 mM
Ionized Calcium, mM	1.19	1.17	-0.02	-1.71%	1.12-1.32 mM
Glucose, mM	7	12.8	5.8	45.31%	3.9-5.8 mM
Urea, mg/dl	6.5	5.9	-0.6	-10.17%	8-26 mg/dl
Creatinine, mg/dl	48	59	11	18.64%	0.6-1.3 mg/dl
Lactate, mM	1.21	6.01	4.8	79.87%	0.36-1.25 mM
Hematocrit, %	48	48	0	0.00%	38-51 %PCV
Hemoglobin*, g/l	163	163	0	0.00%	120-170 g/l
pH	7.401	7.313	-0.088	-1.20%	7.35-7.45
pCO_2, kPa	5.14	4.99	-4.11	-82.36%	4.67 – 6.00 kPa
PO_2, kPa	9.1	6.3	-2.8	-44.44%	10.7-13 kPa
Total CO_2*, mM	25	20	-5	-25.00%	23-27 mM
HCO_3*, mM	23.9	19	-4.9	-25.79%	23-27 mM
Base Excess*, mM	-1	-7	-6	85.71%	(-2)-(+3) mM
O_2* saturation, %	93	80	-13	-16.25%	95-98 %
Urine specific gravity, (g/ml)	1.015	1.025	0.01	0.99%	
Urine pH	8	5	-3	-37.50%	
Urine glucose	Neg.	Neg.	0	0	
Total body water (L)	55.5				
Lean body mass (kg)	72.2				
Fat mass (kg)	26.4				
Bone mass (kg)	3.7				
Body mass (kg)	103				

Note: * calculated, HCO_{3-} Hydrogen carbonate

34.5°C. The pO_2 and the pCO_2 decreased (Table 3). There was a large increase of plasma lactate and plasma glucose levels and a drop of pH. The urine specific gravity increased and the urine pH decreased.

The Second Ice Mile

The swimmer started his second Ice Mile on February 13, 2016, at 10:40 a.m. at a water temperature of 4.8°C. It was sunny, windy and the swimmer had no problems with orientation. His body core temperature was 37.9°C at the start and rose up to 38.1°C after 8 min of swimming (Fig. 2). He completed the second Ice Mile within 42 min and body core temperature was at 36.6°C when he left the water. Thereafter, body core temperature decreased

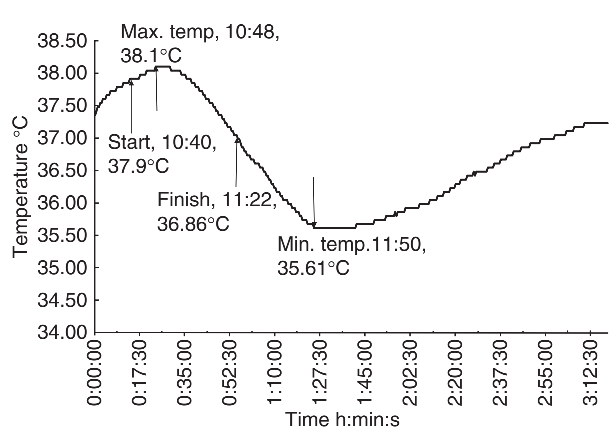

Fig. 2. Change in body core temperature during the second Ice Mile.

Table 4. Blood parameters, bioimpendance and urinary parameters before and after the second Ice Mile

Parameters	Pre	Post	Change absolute	Percent change	Reference Range Arterial
Sodium, mM	139	135	-4	2.88%	138-146 mM
Potassium, mM	5.6	6.9	1.3	-23.21%	3.5-5.5 mM
Chloride, mM	106	109	3	-2.83%	98-109 mM
TCO_2, mM	21	19	-2	9.52%	24-29 mM
Anion Gap*, mM	18	14	-4	22.22%	10-20 mM
Ionized Calcium, mM	1.18	1.12	-0.06	5.08%	1.12-1.32 mM
Glucose, mM	12.5	9.3	-3.2	25.60%	3.9-5.8 mM
Urea, mg/dl	7.5	7.6	0.1	-1.33%	8-26 mg/dl
Creatinine, mg/dl	56	57	1	-1.79%	0.6-1.3 mg/dl
Lactate, mM	1.78	2.99	1.21	-67.98%	0.36-1.25 mM
Hematocrit, %	50	49	-1	2.00%	38-51 %PCV
Hemoglobin*, g/l	170	167	-3	1.76%	120-170 g/l
pH	7.424	7.407	-0.017	0.23%	7.35-7.45
pCO_2, kPa	4.79	5	0.21	-4.38%	4.67 – 6.00 kPa
PO_2, kPa	9.4	7.3	-2.1	22.34%	10.7-13 kPa
Total CO_2*, mM	25	25	0	0.00%	23-27 mM
HCO_3*, mM	23.5	23.6	0.1	-0.43%	23-27 mM
Base excess*, mM	-1	-1	0	0.00%	(-2)-(+3) mM
O_2* saturation, %	94	88	-6	6.38%	95-98 %
Urine specific gravity, (g/ml)	1.015	1.03	0.015	-1.48%	
Urine pH	6	5	-1	16.67%	
Urine glucose	Neg.	Neg.			
Total body water (L)	54.6				
Lean body mass (kg)	71				
Fat mass (kg)	26.7				
Bone mass (kg)	3.7				
Body mass (kg)	101.9				

Note: * calculated, HCO_{3-} Hydrogen carbonate

reaching the nadir at 35.6°C after 38 min. He had a faster recovery (*i.e.* body core temperature rose within two hours to 37°C) with less shivering compared to the first Ice Mile. Lactate increased and blood pH remained within the normal range (Table 4). The pCO_2 before the start was lower than after the first Ice Mile. The potassium level increased into a hyperkalemia (reference range: 3.5-5.5 mM). The sodium level dropped from 139 mM to 135 mM. The urine specific gravity increased and the urine pH decreased.

The Third Ice Mile

The subject started the third Ice Mile on February 13, 2016, at 15:00 p.m. at a water temperature of

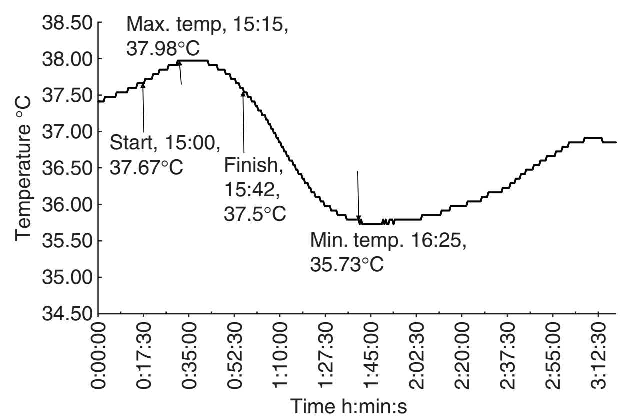

Fig. 3. Change in body core temperature during the first Ice Mile.

Table 5. Blood parameters, bioimpendance and urinary parameters before and after the third Ice Mile

Parameters	Pre	Post	Change absolute	Percent change	Reference Range Arterial
Sodium, mM	139	140	1	-0.72%	138-146 mM
Potassium, mM	5.7	3.7	-2	35.09%	3.5-5.5 mM
Chloride, mM	108	105	-3	2.78%	98-109 mM
TCO_2, mM	22	20	-2	9.09%	24-29 mM
Anion Gap*, mM	16	19	3	-18.75%	10-20 mM
Ionized Calcium, mM	1.17	1.16	-0.01	0.85%	1.12-1.32 mM
Glucose, mM	3.4	12.8	9.4	-276.47%	3.9-5.8 mM
Urea, mg/dl	8.9	8.9	0	0.00%	8-26 mg/dl
Creatinine, mg/dl	48	51	3	-6.25%	0.6-1.3 mg/dl
Lactate, mM	1.31	3.15	1.84	-140.46%	0.36-1.25 mM
Hematocrit, %	43	42	-1	2.33%	38-51 %PCV
Hemoglobin*, g/l	146	143	-3	2.05%	120-170 g/l
pH	7.486	7.34	-0.146	1.95%	7.35-7.45
pCO_2, kPa	4.71	5.66	0.95	-20.17%	4.67 – 6.00 kPa
PO_2, kPa	8.8	8.3	-0.5	5.68%	10.7-13 kPa
Total CO_2*, mM	28	24	-4	14.29%	23-27 mM
HCO_3*, mM	26.7	22.9	-3.8	14.23%	23-27 mM
Base Excess*, mM	3	-3	-6	200.00%	(-2)-(+3) mM
O_2* saturation, %	94	90	-4	4.26%	95-98 %
Urine specific gravity, (g/ml)	1.025	1.03	0.005	0.49%	
Urine pH	6	5	-1	-16.67%	
Urine glucose	Neg.	3.5			
Total body water (L)	51.9				
Lean body mass (kg)	68.4				
Fat mass (kg)	29.7				
Bone mass (kg)	3.5				
Body mass (kg)	102.4				

Note: * calculated, HCO_{3-} Hydrogen carbonate

4.9°C. Leaving the water for the third time, he suffered a deep cut at the right foot. The injury required three stitches and the swimmer decided to stop the project. The recovery was fast with almost no shivering. His body core temperature was at 37.6°C at the start and reached a maximum of 37.9°C after 6 min of swimming (Fig. 3). He completed the third Ice Mile after 41 min and his body core temperature was 37.5°C at the finish. Body core temperature dropped thereafter, reaching the nadir at 35.7°C after 36 min. The hyperkalemia normalized to the lower end of the reference range (Table 5). Glucose and lactate concentration in blood increased and pH decreased. The pCO_2 was even lower than after the second Ice Mile. Urine specific gravity increased and urine pH decreased.

Discussion

This case study demonstrates that an experienced amateur ice swimmer is able to complete three Ice Miles within 15 h without developing hypothermia. The results of different laboratory parameters indicated that ice swimming could lead to a metabolic acidosis, which the swimmer tries to compensate with hyperventilation (*i.e.* leading to respiratory alkalosis).

Body Core Temperature and Hypothermia

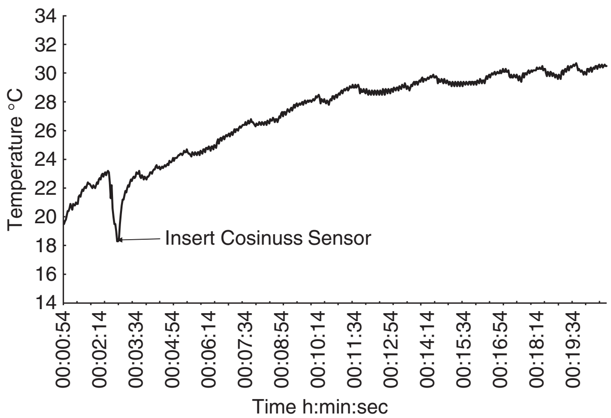

Fig. 4. Change in tympanic temperature after the first Ice Mile.

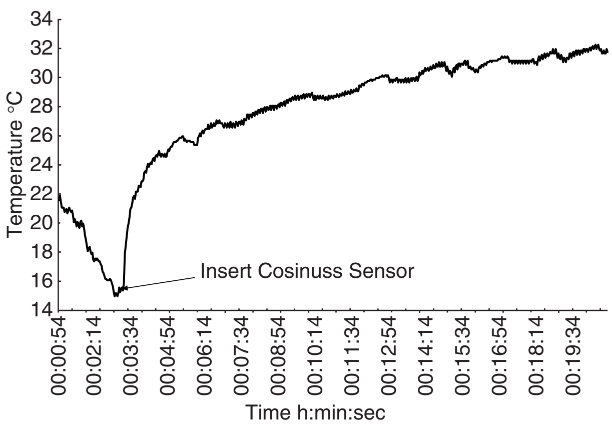

Fig. 5. Change in tympanic temperature after the second Ice Mile.

The first important finding was that the swimmer only developed hypothermia while swimming the first Ice Mile (35.4°C). Nevertheless, he displayed an afterdrop in his body core temperature of 0.8°C after the first, 1.25°C after the second and 1.75°C after the third Ice Mile. This resulted in a mild accidental hypothermia (34.5°C) after the first Ice Mile and physiological hypothermia (<36°C) after the second (35.6°C) and third Ice Mile (35.7°C). This can be explained by the longer duration of the first Ice Mile that the subject completed in 50 min (4). He suffered the largest afterdrop (1.75°C) after the third Ice Mile, where he had maintained the highest body core temperature during the swim.

Additionally, the data show that body core temperature increased within the first min of swimming which parallels the results of a similar study by Rüst *et al.* (28). Noakes *et al.* (25) described this phenomenon as 'anticipatory thermogenesis'. This seems to be a physiological response in trained athletes. Our swimmer's body core temperature reached its maximum between 5, 8 and 15 min after immersion (37.7°C, 38.1°C, and 38.0°C, respectively), with a relative change of 0.2°C-0.3°C.

The prolonged recovery time after the first Ice Mile indicated the limiting duration for cold-water swims. For longer than 50 min, the subject was in water at 4.7°C and he could maintain his body core temperature that was higher than the starting temperature for 20 min before it started to decrease. Another interesting finding was that his body core temperature increased by 0.31°C during the swim and he finished the third Ice Mile with an absolute body core temperature drop of only 0.17°C after 41 min in water of 4.9°C (37.7°C at the start, 38.0°C maximum temperature, 37.5°C at the finish). His high BMI, his wide experience in cold-water swimming and his anticipatory thermogenesis could explain how he maintained this temperature during 41 min in water of 4.9°C (17, 21, 25).

Another finding is that tympanic temperature does not seem suitable for measuring body core temperature during Ice Mile swimming. It substantially overestimates the severity and incidence of hypothermia (Figs. 4 and 5) (27). Tympanic temperature reflects peripheral skin temperature in our setting. The data show how the peripheral temperature gradually recovers over time.

Blood Parameters

The second important finding was that after the second Ice Mile, there was an increase of $[K^+]$ from 5.6 mM to 6.9 mM. This could be explained by a K^+-shift from the muscle cells as shown in a study following intense rowing exercise where plasma $[K^+]$ increased within the first 90 sec and remained high during the exercise (2, 11, 12). Another study regarding the consequences and dynamics in potassium shifts concluded that a rapid and pronounced increase of $[K^+]$ and a substantial loss of $[K^+]$ from the active skeletal muscle were very likely primary causes of fatigue with a fast recovery (29).

His sodium level dropped from 139 mM to 135 mM after the second Ice Mile. The most probable explanation is overdrinking and accidental water swallowing during the Ice Mile (32) in combination with a cold-induced diuresis. In combination with a hyperkaliemia an adrenal insufficiency could also be considered.

Another important finding occurred after the third Ice Mile. Plasma $[K^+]$ decreased from 5.7 mM to 3.7 mM. This can be explained by the post-exercise reuptake of potassium into the muscle (*i.e.* Na^+-K^+ pump) and hormonal control (*i.e.* epinephrine, β-agonists, and insulin) (29). Such low $[K^+]$ levels may pose a cardiovascular risk for individuals susceptible to arrhythmias. The effects of a decreased natriuresis after cold immersion and hypothermia, and changes in H^+ should also be considered as cause of secondary changes in pH and $[K^+]$ (33). However, this finding requires further investigation (2, 16). A systematic review of swimming-related deaths suggested that cardiac arrhythmias were the most likely etiology of a swimming-related death (1).

Metabolic Acidosis

The measured variables indicated that the swimmer developed a metabolic acidosis, which he compensated with a respiratory response. Most probably, the 50 min in ice cold water in the first Ice Mile were an enormous stress for his body. Plasma glucose increased to 12.8 mM (+82.9%) (reference range: 3.9-5.8 mM) without any food intake before the start. Lactate concentration increased from 1.21 mM up to 6.01 mM (reference: <2.3 mM) (31) causing a metabolic acidosis. His body compensated the situation respiratory by decreasing the CO_2 pressure from 9.10 to 4.99 kPa (-45.2%). Our swimmer had no shortness of breath or respiratory distress at any time of the Ice Mile. His rate of breathing was at 30-40/min after each Ice Mile.

Cold Induced Urticaria

There are several cases of cold induced urticaria and anaphylactic reactions described after entering cold waters (3, 13, 22). An IgE-mediated treatment has been shown to be safe and effective in patients with cold urticaria (3, 22).

Strength, Weakness, Limitations and Implications for Future Research

The strengths of this case study are the continuous measurements of body core temperature, swimming time and distance. Numerous biochemical and physiological parameters before and after each Ice Mile give further insight in physiological changes. A weakness is the “bedside”-testing with only one cartridge at the time. This required pricking the earlobe several times with short delays. For better precision, arterial blood could be taken instead of capillary blood (6 mmHg standard error) (33). A direct measure of SpO_2 could be also considered. We also kept no exact track of the entire fluid intake. Another limitation of this study is the single-case design. Future research including a greater number of participants might yield more insights. The increase in plasma glucose and lactate is most probably due to the physical and thermal stress, this stress might be quantified with the measurements of salivary cortisol.

Practical Applications

The results of the current study suggest that is possible for an experienced swimmer with a high BMI to swim consecutive Ice Miles without suffering hypothermia during or after an Ice Mile, when he recovers to 37°C body core temperature between the attempts. In summary, the danger of hypothermia and hypo-/hyperkalaemia could increase the risk of an arrhythmia and based on our data, we do not recommend swimming several Ice Miles. The subject should be in a perfect state of health and have no previous heart condition that could affect his health. Further, a high BMI, a high fat mass and good weather conditions are recommended.

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References

1. Asplund, C.A. and Creswell, L.L. Hypothesised mechanisms of swimming-related death: a systematic review. *Brit. J. Sports Med.* 50: 1360-1366, 2016.
2. Atanasovska, T., Petersen, A.C., Rouffet, D.M., Billaut, F., Ng, I. and McKenna, M.J. Plasma K^+ dynamics and implications during and following intense rowing exercise. *J. Appl. Physiol*. 117: 60-68, 2014.
3. Boyce, J.A. Successful treatment of cold-induced urticaria/anaphylaxis with anti-IgE. *J. Allergy Clin. Immunol.* 117: 1415-1418, 2006.
4. Brannigan, D., Rogers, I.R., Jacobs, I., Montgomery, A., Williams, A. and Khangure, N. Hypothermia is a significant medical risk of mass participation long-distance open water swimming. *Wilderness Environ. Med.* 20: 14-18, 2009.
5. Debaty, G., Moustapha, I., Bouzat, P., Maignan, M., Blancher, M., Rallo, A., Brun, J., Chavanon, O., Danel, V., Carpentier, F., Payen, J.F. and Briot, R. Outcome after severe accidental hypothermia in the French Alps: A 10-year review. *Resuscitation* 93: 118-123, 2015.
6. Dugue, B. and Leppanen, E. Adaptation related to cytokines in man: effects of regular swimming in ice-cold water. *Clin. Physiol.* 20: 114-121, 2000.
7. Eichenberger, E., Knechtle, B., Knechtle, P., Rüst, C.A., Rosemann, T., Lepers, R. and Senn, O. Sex difference in open-water ultra-swim performance in the longest freshwater lake swim in Europe. *J. Strength Cond. Res.* 27: 1362-1369, 2013.
8. Eichenberger, E., Knechtle, B., Knechtle, P., Rüst, C.A., Rosemann, T. and Lepers, R. Best performances by men and women open-water swimmers during the ‘English Channel Swim’ from 1900 to 2010. *J. Sports Sci.* 30: 1295-1301, 2012.
9. Eichenberger, E., Knechtle, B., Rüst, C.A., Knechtle, P., Lepers, R. and Rosemann, T. No gender difference in peak performance in ultra-endurance swimming performance - analysis of the 'Zurich 12-h Swim' from 1996 to 2010. *Chinese J. Physiol.* 55: 346-351, 2012.
10. Graham, J.M. and Keatinge, W.R. Deaths in cold water. *Brit. Med. J.* 2: 18-19, 1978.

11. Hallén, J. K^+ balance in humans during exercise. *Acta Physiol. Scand.* 156: 279-286, 1996.
12. Hart, S.R., Bordes, B., Hart, J., Corsino, D. and Harmon, D. Unintended perioperative hypothermia. *Ochsner J.* 11: 259-270, 2011.
13. Kaplan, A.P., Gray, L., Shaff, R.E., Horakova, Z. and Beaven, M.A. *In vivo* studies of mediator release in cold urticaria and cholinergic urticaria. *J. Allergy Clin. Immunol.* 55: 394-402, 1975.
14. Keatinge, W., Khartchenko, M., Lando, N. and Lioutov, V. Hypothermia during sports swimming in water below 11°C. *Brit. J. Sports Med.* 35: 352-353, 2001.
15. Keatinge, W.R., Prys-Roberts, C. Cooper, K.E., Honour, A.J. and Haight, J. Sudden failure of swimming in cold water. *Brit. Med. J.* 1: 480-483, 1969.
16. Kjeldsen, K. Hypokalemia and sudden cardiac death. *Exp. Clin. Cardiol.* 15: 96-99, 2010.
17. Knechtle, B., Christinger, N., Kohler, G., Knechtle, P. and Rosemann, T. Swimming in ice cold water. *Ir. J. Med. Sci.* 178: 507-511, 2009.
18. Knechtle, B., Nikolaidis, P.T., Rosemann, T. and Rüst, C.A. Performance trends in age group breaststroke swimmers in the FINA World Championships 1986-2014. *Chinese J. Physiol.* 59: 247-259, 2016.
19. Knechtle, B., Rosemann, T., Lepers, R. and Rüst, C.A. Women outperform men in ultradistance swimming: the Manhattan Island Marathon Swim from 1983 to 2013. *Int. J. Sports Physiol. Perform.* 9: 913-924, 2014.
20. Knechtle, B., Rosemann, T. and Rüst, C.A. Women cross the 'Catalina Channel' faster than men. *Springerplus* 4: 332, 2015.
21. Knechtle, B., Rosemann, T. and Rüst, C.A. Ice swimming and changes in body core temperature: a case study. *Springerplus* 4: 394, 2015.
22. Mazarakis, A., Bardousis, K., Almpanis, G., Mazaraki, I., Markou, S. and Kounis, N.G. Kounis syndrome following cold urticaria: the swimmer's death. *Int. J. Cardiol.* 176: e52-e53, 2014.
23. McCullough, L. and Arora, S. Diagnosis and treatment of hypothermia. *Am. Fam. Physician.* 70: 2325-2332, 2004.
24. Molnar, G.W. Survival of hypothermia by men immersed in the ocean. *J. Am. Med. Assoc.* 131: 1046-1050, 1946.
25. Noakes, T.D., Dugasa, L.R., Tuckera, R., Oksab, J., Dunnc, J., van der Merwec, B.S., Dirkerc, J.A., Porvarid, K. and Smolandere, J. Body temperatures during three long-distance polar swims in water of 0–3°C. *J. Therm. Biol.* 34: 23-31, 2009.
26. Nuckton, T.J., Claman, D.M., Goldreich, D., Wendt, F.C. and Nuckton, J.G. Hypothermia and afterdrop following open water swimming: the Alcatraz/San Francisco swim study. *Am. J. Emerg. Med.* 18: 703-707, 2000.
27. Polderman, K.H. Mechanisms of action, physiological effects, and complications of hypothermia. *Crit. Care Med.* 37: S186-S202, 2009.
28. Rüst, C.A., Knechtle, B. and Rosemann, T. Changes in body core and body surface temperatures during prolonged swimming in water of 10°C—a case report. *Extrem. Physiol. Med.* 1: 8, 2012.
29. Sejersted, O.M. and Sjøgaard, G. Dynamics and consequences of potassium shifts in skeletal muscle and heart during exercise. *Physiol. Rev.* 80: 1411-1481, 2000.
30. Schaub, P., Knechtle, B., Rüst, C.A. and Rosemann, T. Differences in swimming speed between short and long course from 50 m to 1,500 m in elite female and male Swiss freestyle age group swimmers. *Adapt. Med.* 7: 186-195, 2015.
31. Wacharasint, P., Nakada, T.A., Boyd, J.H., Russell, J.A. and Walley, K.R. Normal-range blood lactate concentration in septic shock is prognostic and predictive. *Shock* 38: 4-10, 2012.
32. Wagner, S., Knechtle, B., Knechtle, P., Rüst, C.A. and Rosemann, T. Higher prevalence of exercise-associated hyponatremia in female than in male open-water ultra-endurance swimmers: the 'Marathon-Swim' in Lake Zurich. *Eur. J. Appl. Physiol.* 112: 1095-1106, 2012.
33. Zavorsky, G.S., Cao, J., Mayo, N.E., Gabbay, R. and Murias, J.M. Arterial versus capillary blood gases: a meta-analysis. *Respir. Physiol. Neurobiol.* 155: 268-279, 2007.